ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 60 (2013) 28 – 33
Procedia Engineering
www.elsevier.com/locate/procedia

6th Asia-Pacific Congress on Sports Technology (APCST)

Feasibility of using virtual and body worn inertial sensors to detect whole-body decelerations during stopping

William H. Gageler[a*], David Thiel[a], Jonothan Neville[a,b], Daniel A. James[a,b,c]

[a]*Center for Wireless Monitoring and Applications, Griffith University, Nathan 4111, Australia*
[b]*Center of Excellence for Applied Sport Science Research, Queensland Academy of Sport, Brisbane, QLD, Australia*
[c]*Queensland Sports Technology Cluster*

Received 20 March 2013; revised 6 May 2013; accepted 9 May 2013

Abstract

The aim of this study was to explore the use of inertial sensors for determining the rate of deceleration of an athlete during controlled breaking during over-ground running. This study will investigate the application of inertial sensors in identifying kinematic parameters to examine the effects of shock attenuation through the body. This study consisted of participants performing a number of sub-maximal runs and stopping within given distances (6m and 3m) to control the rate of deceleration. Kinematic data was recorded using a combination of motion capture and custom build inertial sensors attached to the participants' distal fibulas and worn in a commercially available sports vest. From the data, tibia accelerations increased by 32% while peak upper torso accelerations decreased by 0.3% resulting in an overall increase in shock attenuation of 21%. This increase in attenuation was predominantly due to the ankle to knee attenuating 39% more shock, while the knee to sacrum and sacrum to upper torso both decreased by 6% and 2% respectively. As both the inertial sensor acceleration and motion capture derived acceleration displayed similar trends in shock absorption, it is difficult to detect variations in the rate of stopping using only peak impact parameters from an inertial sensor unit located on the upper torso. This is due to the varying shock attenuation capabilities of the lower joints in particular the knee which absorbed the majority of the shock under both stopping conditions.

Selection and peer-review under responsibility of the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University

Keywords: Accelerometer; inertial sensor; running; stopping; breaking; decelerations; shock attenuation; impact

* Corresponding author. Tel.: +61 (0)7 3735 5084; fax: +61 (0)7 3735 5384.
E-mail address: william.gageler@griffithuni.edu.au

Selection and peer-review under responsibility of the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
doi:10.1016/j.proeng.2013.07.040

1. Introduction

Running is one of the most commonly occurring activities in sport and as a result the biomechanical and performance aspects have received significant attention by athletes, coaches and researches alike [1-4]. The majority of this research however, is based on running at constant speeds while there is a lack of research on rapidly changing speeds, various rates of deceleration and stopping.

Research undertaken to examine the effects of changing speeds while walking [5] has shown that there is a positive relationship to braking impulses and rates of deceleration, however, it is unclear as to how this relationship translates to running and rapidly changing speeds. Looking at the run-to-walk transition and the associated vertical ground reaction forces there are unique characteristics present [1]. These characteristics included peak force and time to peak force which both reduced dramatically with steps approaching the run-to-walk transition. This paper was however, limited to examining the resulting ground reaction forces of decelerations ranging from -0.4 m/s^2 to -1.2 m/s^2.

From the two sources mentioned, it is clear that the process of transitioning from running to a stop is unique when compared to steady-state running and that it is very likely that the changes in characteristics observed will be related to the rate at which this transition occurs.

Previous studies [2] have used shock attenuation as a means of calculating the amount of impact energy absorbed while running at various stride lengths. This is relevant to this study as preferred stride length has been shown to change with speed [3], therefore, it is likely that the process of rapidly decelerating will see a wide range of stride lengths occurring. When combining the effects of stride length on shock attenuation, as well as the increases in breaking impulses expected from decelerations [5] it is reasonable to assume the shock attenuation will be influenced. The change in shock attenuation would in turn affect the workload on the various joints and muscles involved.

Overall the aim of this study is to explore the feasibility of using simple kinematic parameters obtained from a single inertial sensor to determine the rate of breaking and stopping and to observe which limbs are most affected by the various rates of deceleration furthermore, this research will explore the contributions of each segment in absorbing the forces associated with breaking.

2. Methods

2.1. Instrumentation

This study recorded data from two different types of inertial sensors and a motion capture system. Firstly, a custom build tri-axel +/-8g accelerometer logging at 100Hz [6] was worn in a commercially available sports vest which positioned the sensor around the middle to upper thoracic vertebrae.

The second type of inertial sensor used was a custom built device containing a 100g accelerometer, attached to measure vertical accelerations logging at 200Hz down sampled to 100Hz to allow comparison. Two of these sensors were used with each one being attached to the distal Fibulas. The custom built 100g accelerometer inertial sensors allowed for the tracking of the ground impacts accelerations at the ankle as this force greatly exceeded the range of the +/-8g units.

The inertial sensor data was recorded in conjunction with an OptiTrack motion capture system consisting of 8 cameras sampling at 100Hz. Markers were placed at the same locations as the inertial sensors previously mentioned as well as the lateral epicondyles of the femurs and sacral foramen.

2.2. Data collection and analyses

Data was collected from three subjects, with running experience ranging from recreational to professional. To collect the data participants performed several trials each consisting of a synchronization routine and a run at a self-selected pace and distance. Participants were requested to keep both the pace and distance consistent across all the trials, however two different stopping conditions were imposed. These conditions were that participants were required to stop within a 6m distance and a 3m distance. This process was repeated until 10 complete stopping transitions had been recorded at each distance.

This study was conducted in accordance with the National Statement on Ethical Conduct on Research Involving Humans. Griffith University Human Research Ethics Committee reference number ENG/15/12/HREC.

Limited by the capture volume of the motion capture system, the 6m trials were offset by 3m so breaking patterns could be reconstructed and analyzed. Essentially runs were performed which captured the first half of the stopping process with the following 3m outside the capture volume, all transition markers were then moved back 3m and the runs repeated to capture the second half of the stopping process with the first 3m occurring before entering the capture region. Fig 1 shows an example of the offset required to capture the entirety of each stopping distance.

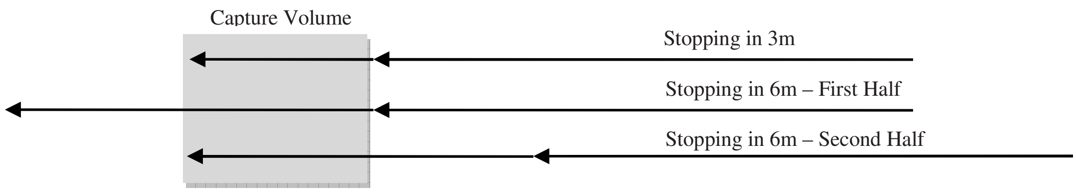

Fig 1. Illustration of the offset that was needed in order to capture the entire stopping distance for 6m

The offset for the 6m stopping distance meant that twice the number of 6m runs were required. Therefore, each subject performed 20 runs with a 6m stopping distance and 10 runs with a 3m stopping distance.

Upon collection, the motion capture data was exported into C3D files that were then imported into Matlab for processing. The ADAT data structure [7] was used to store the participant information, inertial sensor data and motion capture data. The inertial sensor data was then orientated to match the ISB recommendations for standardization in the reporting of kinematic data [8]. Once orientated each device was synchronized with the nearest proceeding markers from the synchronization routine to ensure all sources of data remained synchronized for the entire trial.

Each run was processed on a step-by-step basis to extract the peak impact parameters from the inertial sensor data and corresponding peaks in the motion capture acceleration. Once collected the first step of the stopping process was labeled as step 0 and step-by-step comparison made between measurement locations and rates of stopping for each subsequent step.

3. Results and discussion

Fig 2 shows the results of the peak vertical accelerations for the upper torso and ankle as well as the shock attenuation that occurred for each step. Examining the change produced due to the shorter stopping distance showed that while the ankle accelerations increased by a maximum of 32% for the 3m trial, the upper torso accelerations decreased by 0.3%. This non-corresponding influence on the upper torso accelerations was attributed to an increased shock attenuation of 21% for the 3m stopping distance.

As previously discovered in the literature [3] similar trends are observed between the increased ankle impact peaks, increased shock attenuation and little change occurring in upper torso acceleration impact peaks. At constant speeds however, increased ankle acceleration impact peaks and shock attenuation were related to increased speeds, whereas in this research they are attributed to increased rates of stopping.

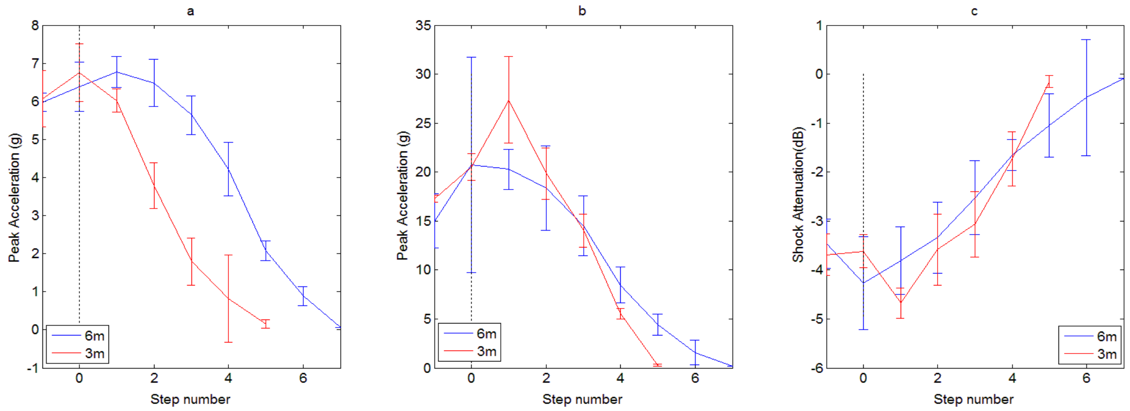

Fig 2. (a) Peak accelerations measured at the upper torso using physical accelerometers. (b) Peak accelerations measured at the ankles using physical accelerometers. (c) Shock attenuation between the upper torso and ankle using physical accelerometers. All figures are the averages for the 30 values (3 subjects, 10 repetitions).

Using the motion capture markers to derive the acceleration data from changes in position and time allowed the maximum impact peaks for each marker to be calculated; as well as the ankle-to-marker shock attenuation and marker-to-marker shock attenuation as shown in Fig 3.

Observing the shock attenuation from the ankle marker to the knee marker, sacrum marker and upper torso marker respectively (Fig 3, (b)) showed that the majority of attenuation was occurring early in the 3m trial whilst remaining relatively constant across the 6m trial. For the first five steps of each stopping distance the maximum shock attenuation increase in the 3m trial by 17%, 23% and 39% at the upper torso, sacrum and knee. Comparing the ankle to upper torso shock attenuation for both the physical and virtual accelerations resulted in similar values for each.

To determine which body segments were responsible for attenuating the majority of the shock, the marker-to-marker shock attenuation was measured (Fig 3, (c)). This allowed for comparisons between the ankle-to-knee, knee-to-sacrum and sacrum-to-upper torso shock attenuation to be made. It was measured that the ankle-to-knee attenuation increased by 9% while both the knee-to-sacrum and sacrum-to-upper torso decreased by 6% and 2% respectively. This meant that for the shorter stopping distance the shock attenuation characteristics of the body changed to reduce the attenuation at the sacrum and back by increasing the shock absorbed by the knee.

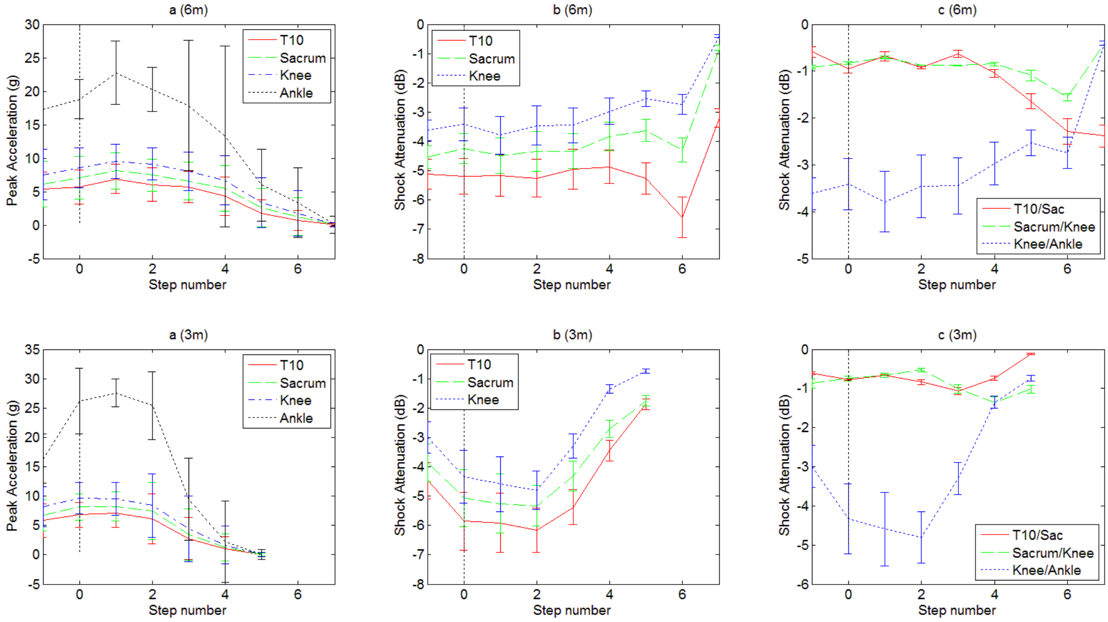

Fig 3. (a) Peak accelerations measured for each marker using virtual accelerometers. (b) Shock attenuation between each marker and the ankle using virtual accelerometers (c) Shock attenuation between each marker and the marker below it in the chain going up the body using virtual accelerometers. All figures are the averages for the 30 values (3 subjects, 10 repetitions).

The percentage of total shock absorbed by each segment was calculated, (Table 1), to compare the differences that occurred during the two stopping distances. This showed that the ankle-to-knee attenuation values ranged from 68-77% of the total shock corresponding to previous findings by Kim, et al. [4] for knee shock attenuation while running at constant speeds.

Table 1. Percentage of total shock attenuated for each marker

Stopping Distance	Ankle-Knee	Knee-Sacrum	Sacrum-Upper Torso
6m	68.3%	15.4%	16.3%
3m	76.5%	10.8%	12.7%
Difference	8.2%	-4.6%	-3.6%

As the ankle-to-knee attenuation was considerably greater than the other segments for each stopping distance, it can be concluded that the knee is the major shock absorbing joint for the body, as supported by [2]. This helps to explain why the knee and lower leg are the most commonly hospitalized sports injuries with a major cause being musculoskeletal damage [9].

An increase of 8% in total shock absorption was measured between the ankle and knee when comparing the 6m and 3m stopping distances. This equates to an increased workload for the knee and could potentially result in earlier onset of muscle and joint fatigue when multiple rapid stops are performed over a short timeframe.

4. Conclusion

From the results and discussion it has been shown that increasing the rate of deceleration by imposing shorter stopping distances will increase the peak ankle impact forces considerably. This is achieved while maintaining relatively consistent upper torso accelerations thus making it difficult to detect the rate of stopping using only peak upper torso impact forces. Consistent upper torso accelerations were observed at both stopping distances indicating the majority of shock absorption was isolated to the other measured segments.

Examining the source of the shock attenuation capabilities identified the knee as being the major contributor under both conditions with faster stopping rates resulting in the knee absorbing greater forces and percentage of total forces. From this it can be concluded that frequent and rapid stops may result in earlier onset of muscle and joint fatigue as well increasing the possibility of injury.

References

[1] L. Li and J. Hamill, "Characteristics of the vertical ground reaction force component prior to gait transition," *Research quarterly for exercise and sport,* vol. 73, pp. 229-237, 2002.

[2] T. R. Derrick, J. Hamill, and G. E. Caldwell, "Energy absorption of impacts during running at various stride lengths," *Medicine & Science in Sports & Exercise,* vol. 30, p. 128, 1998.

[3] J. A. Mercer, J. Vance, A. Hreljac, and J. Hamill, "Relationship between shock attenuation and stride length during running at different velocities," *European Journal of Applied Physiology,* vol. 87, pp. 403-8, 2002.

[4] W. Kim, A. S. Voloshin, and S. H. Johnson, "Modeling of heel strike transients during running," *Human Movement Science,* vol. 13, pp. 221-244, 1994.

[5] C. L. Peterson, S. A. Kautz, and R. R. Neptune, "Braking and propulsive impulses increase with speed during accelerated and decelerated walking," *Gait & Posture,* vol. 33, pp. 562-567, 2011.

[6] D. A. James, R. I. Leadbetter, M. R. Neeli, B. J. Burkett, D. V. Thiel, and J. B. Lee, "An integrated swimming monitoring system for the biomechanical analysis of swimming strokes," *Sports Technology,* vol. 4, pp. 141-150, 2011/08/01 2011.

[7] D. A. James and A. Wixted, "ADAT: A Matlab toolbox for handling time series athlete performance data," *Procedia Engineering,* vol. 13, pp. 451-456, 2011.

[8] G. Wu and P. R. Cavanagh, "ISB recommendations for standardization in the reporting of kinematic data," *J Biomech,* vol. 28, pp. 1257-1262, 1995.

[9] L. Flood, J. E. Harrison, Australian Institute of Health and Welfare., and Flinders University., *Hospitalised sports injury, Australia 2002-03*. Canberra: Australian Institute of Health and Welfare, 2006.